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The permissible level of lower sideband radiation from a UHF TV transmitter

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THE BRITISH BROADCASTING CORPORATION

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Summary

Amplitude-modulated television signals are transmitted with a vestigial lower sideband for reasons of spectrum economy. The question of the degree of suppression of the lower sideband needed to avoid interference to reception of the lower adjacent channel has been re-examined by subjective tests. The currently accepted protection ratio of 3 dB for interference coming from the upper adjacent channel is verified. The existing specification for lower sideband suppression is found to be still appropriate, taking advantage of the low levels of high-frequency components contained even in critical pictures. Maximum scope for transmitter efficiency improvements is allowed consistent with the re-use of channels in a network being limited by receiver performance.

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1. INTRODUCTION

The vision component of a TV signal is broadcast using amplitude modulation. It is transmitted with a vestigial lower sideband for reasons of spectrum economy. Fig. 1 is a diagram of the spectrum for System I/PAL at u.h.f., showing two adjacent channels. It can be seen that if the lower sideband is imperfectly suppressed, interference may be caused to the lower adjacent (wanted) channel.

A viewer watching the lower of the two channels will perceive the interference as patterning on the picture. It is reasonable to require that if the interference is continuous it should not exceed the level at which it is just perceptible.

The visibility of interference depends on the ratio of the wanted and interfering signal powers at the input of the receiver. The ratio at which the interference becomes visible depends on the performance of both the transmitter and the receiver. For the transmitter, the suppression of the out-of-band portion of the lower sideband (which conveys no useful information) is the relevant parameter. For the receiver, it is immunity to interference from the upper adjacent vision carrier (which cannot be filtered out at the transmitter) that matters most.

This Report presents results of an experiment designed to assess the permissible level of lower sideband radiation from a TV transmitter. The assessment was based on subjective tests carried out with domestic receivers.

This question was studied about twenty years ago[1] and the transmitter specification put forward was adopted by the broadcasters. It was felt necessary to review the question for a number of reasons. Firstly, the protection ratio assumed by Wharton differs from the value currently applied. Secondly, newer designs of transmitter may radiate the lower sideband at a higher level than earlier designs. Thirdly, the use of electronic graphics in television production is increasing and this may lead to a change in the spectral content of pictures.

2. PLANNING CONSIDERATIONS AND THE CHARACTERISTICS OF TRANSMITTERS

To cover all the areas that are to be served, many transmitters are needed. There are a limited number of channels available so that the more often a channel can be re-used, the more complete the coverage can be. The re-use of channels is limited by interference considerations.

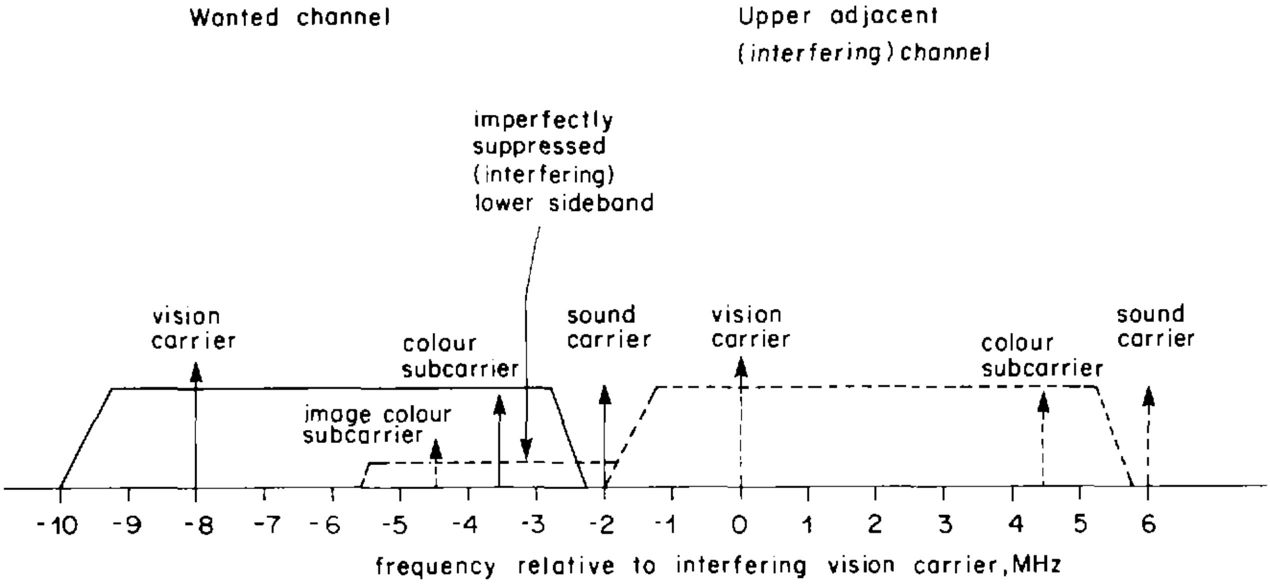

Fig. 1 – Spectrum of two adjacent u.h.f. channels.

In the particular case of adjacent-channel interference (a.c.i.) with which this Report is concerned, it is desirable that the performance of the receiver should be the limiting factor, and not the performance of the transmitter. This will allow the spectrum to be used as efficiently as possible.

Thus the protection ratio should be verified with an interfering signal which has a well-suppressed lower sideband. For this purpose the protection ratio is the ratio of wanted to interfering signal powers at which interference is just perceptible.

Once the protection ratio is established the usual procedures can be followed to plan a service that will be satisfactory.

The lower sideband of a transmission does not need to be completely suppressed but it needs to be below the level at which interference is just perceptible. Making the limit tighter than this, offers no planning advantage and has cost implications.

At a transmitter, the vestigial sideband filtering is carried out at low power for reasons of capital cost. The sideband suppression of the filter is considerably better than the overall specification for the transmitter. Any odd-order non-linearity or a.m. to p.m. conversion in the following power amplifier will regenerate the lower sideband. This is of particular concern where there is a klystron amplifying the vision signal alone. The efficiency of vision klystrons has been increased by operating closer to saturation and increasing the amount of precorrection. The video performance is satisfactory but the suppressed part of the lower sideband is regenerated at a higher level because it lies where precorrection is ineffective, outside the passband of the klystron. Thus the limit on radiation of the lower sideband may limit the efficiency that can be achieved by a vision klystron, and so the specification should be no more stringent than necessary. It is apparent that there could be an increase in the level of the lower sideband radiated from an existing transmitting station if the mode of operation is changed, provided that the level remains within the specification.

It is necessary to consider whether such an increase in the level of the out-of-channel portion of the lower sideband could lead to viewers perceiving interference. If the protection ratio is determined by the performance of the receiver, it means that the upper adjacent vision carrier is the dominant source of interference. A certain standard of receiver performance is assumed when determining the protection ratio, and this value of protection ratio, in turn, is assumed when determining the sideband suppression. A possible problem arises if a receiver performs better than the assumed standard, because the lower sideband of the upper adjacent channel may then become the dominant source of interference. If a viewer with such a receiver is receiving a transmission from outside the service area or using a sub-standard aerial installation, and there is an interfering transmission on the upper adjacent channel which has a well-suppressed lower sideband then the ratio of wanted to interfering signal powers at the input to the receiver may be inferior to the assumed protection ratio. It is under these circumstances that interference may be seen if the level of the lower sideband is increased, even though the transmitter is still within specification. However, such circumstances do not constitute a planned service and should be very rare so that they need not be allowed for in setting the specification.

3. EXPERIMENTAL WORK

In the first set of subjective tests a number of domestic receivers were tested with an interfering signal which had a well-suppressed lower sideband. The purpose of this test was to verify the currently-accepted value of the a.c.i. protection ratio.

In the second set of tests the level of the out-of-channel portion of the lower sideband of the interfering signal was varied (see spectrum, Fig. 1). The ratio of vision carrier powers was set at the protection ratio limit and the sideband suppression was reduced until interference was just perceptible. This gave the sideband suppression that is required at a transmitter.

This procedure is in accordance with the principles discussed in Section 2 concerning the way in which the specification should be determined.

3.1 Experimental Arrangement

A block diagram of the equipment is shown in Fig. 2. The outputs of two sound/vision modulators, tuned to channels 64 and 65, were combined and fed to a receiver. The interfering signal was on channel 65. The levels of both signals could be adjusted.

The modulator for the interfering signal was specially modified to incoporate one of two filters at i.f. The first filter, referred to as the USB filter (i.e. upper sideband), had a vestigial sideband response in line with current transmitter practice. The spectrum of channel 65 with the USB filter in circuit is shown in Fig. 3 with 0 to 5.5 MHz line sweep as the picture signal. The chosen degree of sideband suppression was expected to be adequate and this was confirmed during the tests. The USB filter was used

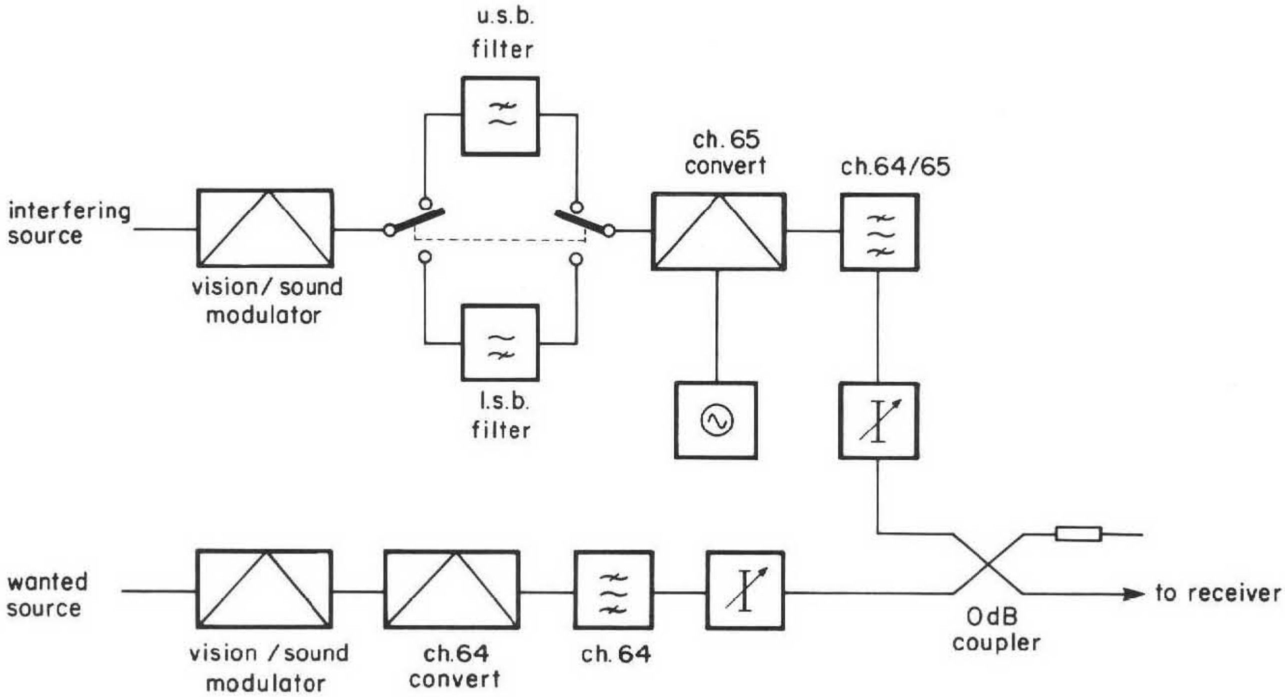

Fig. 2 – Block diagram of apparatus for adjacent channel interference tests.

in the first part of the tests, to check that the protection ratio currently applied is appropriate.

The passband of the second filter, referred to as the LSB filter (i.e. lower sideband), essentially corresponded to the region beyond the vestigial sideband. The spectrum of channel 65, again with line sweep as the picture signal, but with the LSB filter in circuit, is shown in Fig. 4. This interfering signal is different from that shown in Fig. 1 and avoids two problems.

(a) If both the chosen level of lower sideband, and the vision carrier were present it might be difficult to tell which was causing interference.

(b) It would be difficult to keep the power in the vision carrier region at a constant level (determined by the protection ratio criterion) while the power in the lower sideband region was varied.

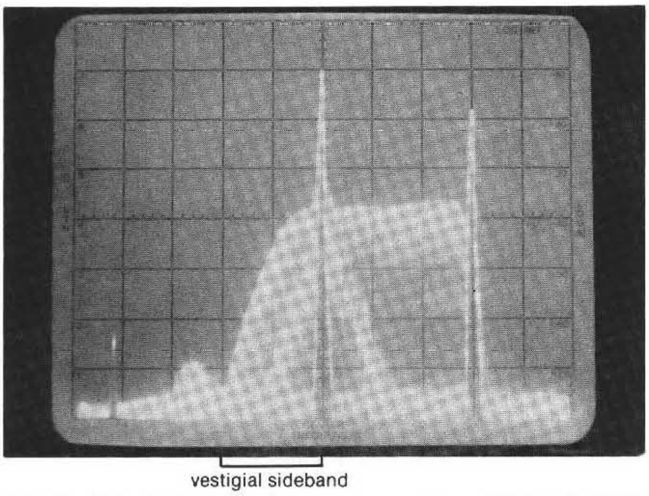

Fig. 3 – Interfering signal spectrum on channel 65 with USB filter selected.

Vertical scale : 10 dB/div.
Horizontal scale : 2 MHz/div.
Centre frequency : 823.25 MHz.
Resolution bandwidth : 100 kHz.

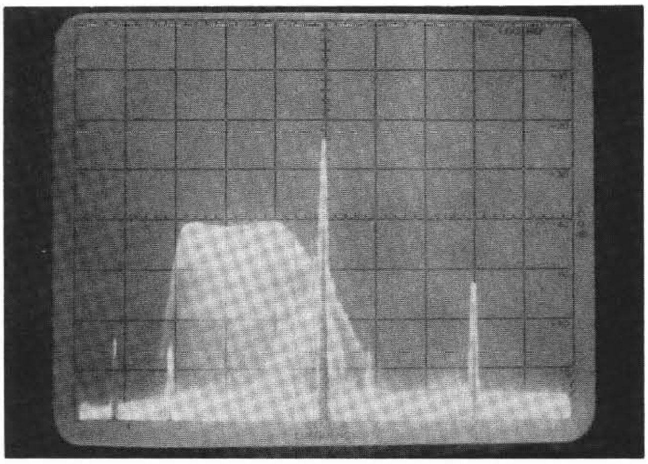

Fig. 4 – Interfering signal spectrum on channel 65 with LSB filter selected.

Vertical scale : 10 dB/div.
Horizontal scale : 2 MHz/div.
Centre frequency : 823.25 MHz.
Resolution bandwidth : 100 kHz.

The effective sideband suppression is given by the ratio between the vision carrier power in the absence of the LSB filter, and the vision carrier power which would exist at the protection-ratio limit. The frequency responses of the filters are shown in Fig. 5. Note that the i.f. spectrum is inverted because the local oscillator is high. The modulator for the wanted channel produced a double sideband signal, but this is of no consequence in this experiment. The spectrum at i.f. is shown in Fig. 6.

The r.f. input level to the receiver was 3 mV peak sync (terminated) for the wanted signal. The sound/vision ratio was set to −10 dB because the UK is currently changing to this ratio from −7 dB. Even though the sound/vision ratio was −10 dB in the tests, the picture always required more protection than the sound. At a sound/vision ratio of −7 dB, the a.c.i. protection ratio would be slightly greater than at −10 dB.

Three values of the frequency spacing between the vision carriers were used: 8 MHz and 8 MHz ±26 kHz. The nominal spacing was maintained to within 1 kHz. This corresponds to the non-precision control usually applied to transmitters in the UK. The offset of 26 kHz is equal to five thirds of line frequency. Such offsets are used to reduce the visibility of co-channel interference. For brevity the phrase 'at zero offset' will be used to indicate a spacing of 8 MHz, and similarly 'at plus or minus 5/3 line offset' indicates a spacing of 8.026 MHz or 7.974 MHz respectively.

3.2 Procedure

The pictures were assessed on a small number of domestic receivers. The choice of receiver may affect the visibility of interference from the vision carrier but is unlikely to affect the visibility of interference from the lower sideband because the frequencies are in the passband of the receiver.

The assessments were made by skilled observers who were asked to judge the picture critically and to adjust the level of interference until it was just perceptible. The viewing conditions were, as far as possible, in accordance with CCIR recommendations[2] except that the viewing distance was four times picture height. Care was needed over the adjustment of the display because it was found to have a significant effect on the visibility of interference.

The picture material for the interfering signal was:

1. 100% colour bars.
2. 0 to 5.5 MHz line sweep, 700 mV p-p.
3. Test card G (see Fig. 7).
4. A selection of still pictures including 'Tree', 'Guardsman', 'Concorde' (see Figs. 8–10) and a teletext page.

The picture material for the wanted signal included:

1. Test Card F, 'Formal Pond' (see Fig. 11) and other EBU test slides.
2. Off-air moving pictures.

3.3 Results

The patterning caused by the interference is most visible in plain areas of the picture that have a mid-to-low luminance level. Of the standard test

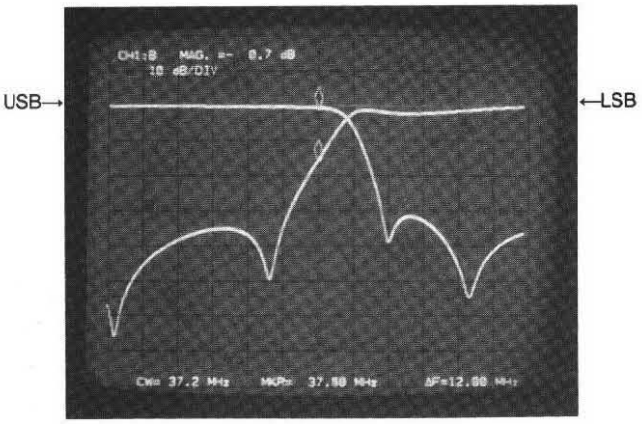

Fig. 5 – Frequency responses of USB and LSB filters – note spectrum inversion.
Vertical scale : 10 dB/div.
Horizontal scale : 2 MHz/div.
Marker at vision carrier frequency (37.5 MHz)

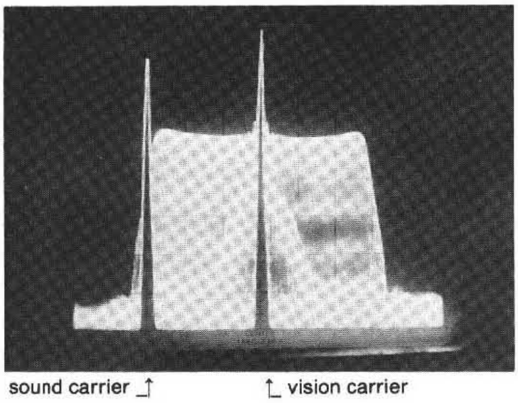

Fig. 6 – IF output spectrum of modulator (double sideband vision) – note spectrum inversion.
Vertical scale : 10 dB/div.
Horizontal scale : 2 MHz/div.
Centre frequency : 37.5 MHz.
Resolution bandwidth : 100 kHz.

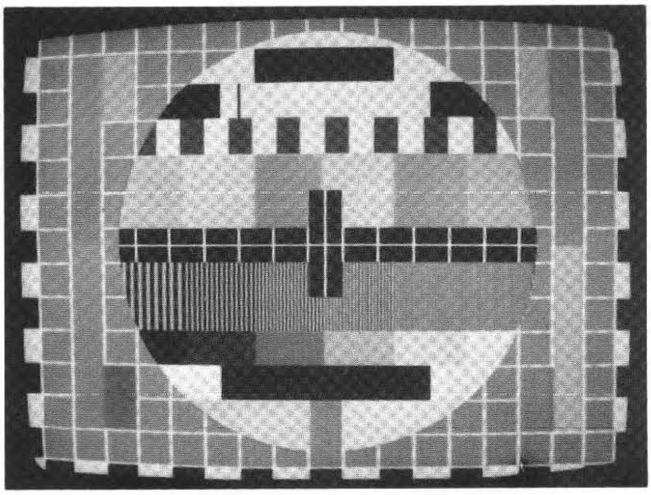

Fig. 7 – Test Card G.

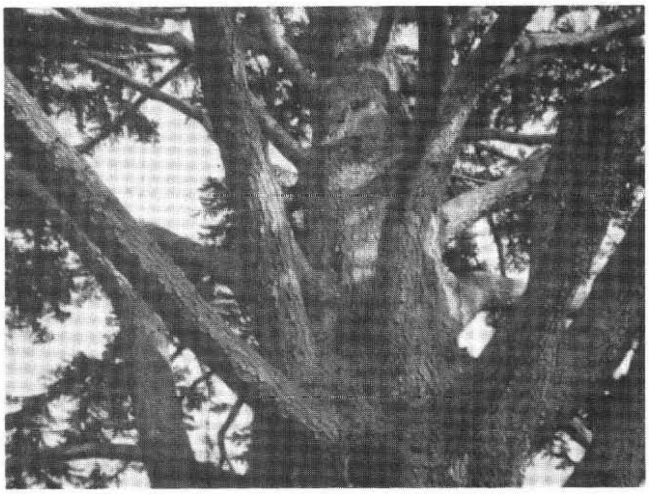

Fig. 8 – Tree.

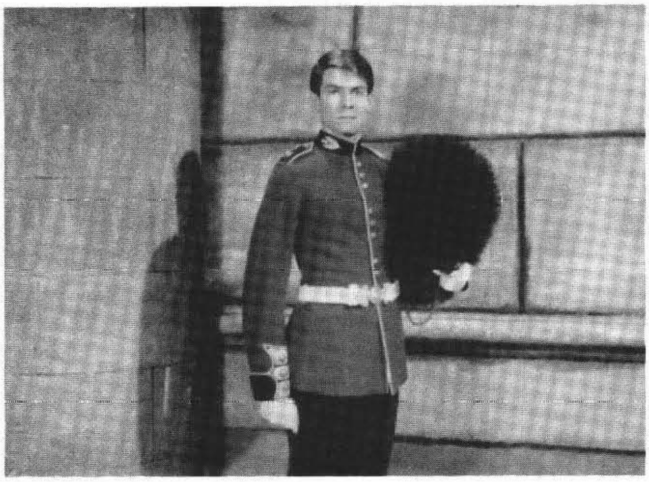

Fig. 9 – Guardsman.

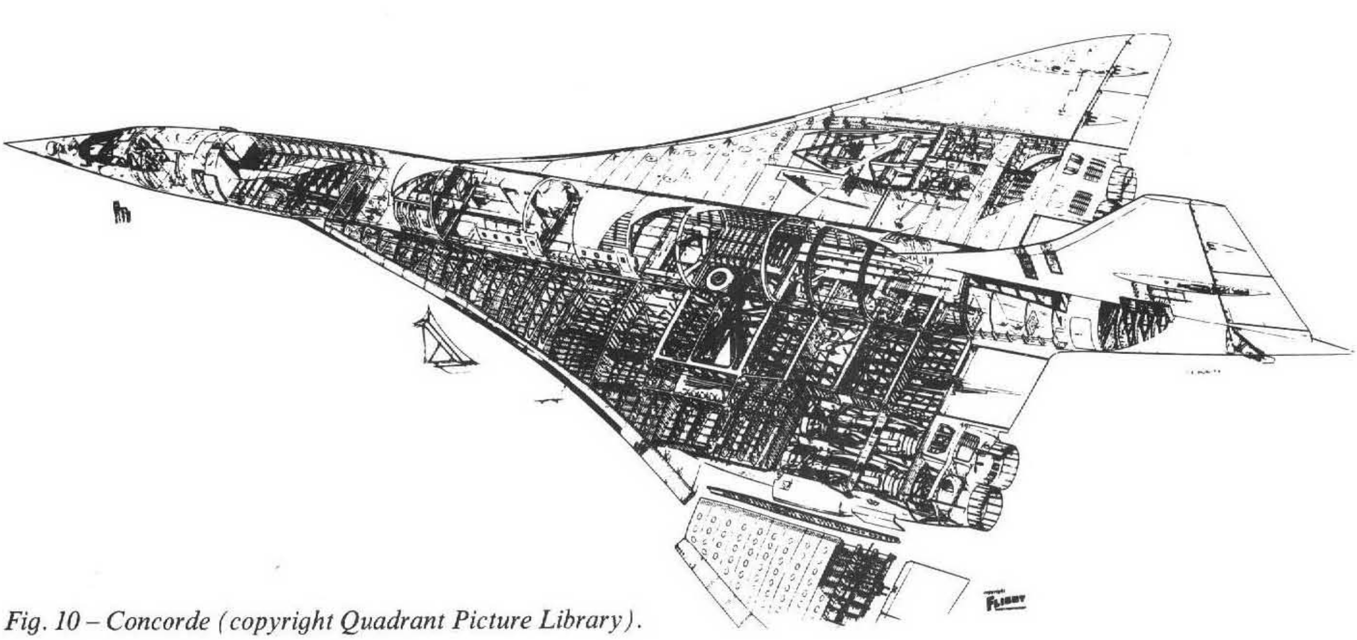

Fig. 10 – Concorde (copyright Quadrant Picture Library).

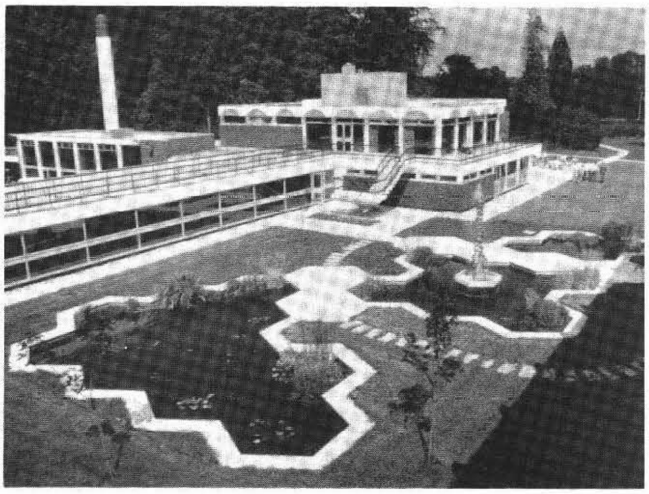

Fig. 11 – Formal Pond.

slides available, Formal Pond was found to be the most critical for showing interference. It was also found to be representative of critical off-air pictures. The quantitative results were obtained with Formal Pond as the wanted picture.

3.3.1 Adjacent channel interference protection ratio

With the USB filter in circuit, the most visible patterning was vertical bars at 2 MHz, seen when the interfering signal was black level at zero offset and the wanted sound carrier was unmodulated. The patterning appears to be generated from the wanted sound carrier and the interfering vision carrier by non-linearity in the receiver. The protection ratio requirement varies with the signal level for some receivers but not for others, depending on where the non-linearity arises in the receiver.

The protection ratio requirement was +3 dB or slightly less, for just perceptible interference (i.e. the wanted vision carrier power is 3 dB more than the interfering vision carrier power). This confirms the currently-accepted limit of 3 dB which was derived from the limit of −12 dB given by the CCIR for occasional interference^3.

3.3.2 Sideband suppression required

Interference from the lower sideband was assessed with the LSB filter in circuit. The offset was seen to affect the visibility of interference. Luminance-to-luminance and chrominance-to-chrominance interference are more visible at zero offset. Luminance-to-chrominance and chrominance-to-luminance interference are most visible at plus or minus 5/3 times line frequency offset, depending on which colour difference signal is involved. The U-axis and V-axis components of the subcarrier will be referred to as the red and blue chrominance signals respectively.

3.3.2.1 Interference from representative pictures

A collection of still pictures, including standard EBU test slides, was available to be used as the interfering signal. The pictures likely to cause the worst interference were chosen for the tests. The criteria of choice were large areas of saturated colour and/or much fine detail (i.e. strong high-frequency content).

For all the pictures, a PAL coder with a luminance notch at 4.43 MHz was used. This tends to reduce the amount of high-frequency luminance in the picture.

The three worst slides in the tests were the EBU test slide 'Tree' which required 14 dB of sideband suppression; and two BBC in-house slides known as 'Guardsman' and 'Concorde' which required 18 dB and 14 dB of sideband suppression respectively. With the in-house slides, although the fine detail caused luminance-to-luminance interference at zero offset, the most visible interference was chrominance-to-luminance, at +5/3 line offset for one slide where the blue chrominance signal predominated and at −5/3 line offset for the other slide where the red chrominance signal predominated. With 'Tree' the interference again appeared to be subcarrier patterning but this time it was most visible at zero offset, possibly because the red and blue chrominance signals were present in roughly equal proportions.

A teletext page was also used as the interfering picture. It was taken in RGB form from a teletext decoder and the colours were 100% saturated (as against the 75% amplitude normally broadcast). Interference from coloured lettering was much more visible than interference from white lettering. The most visible interference came from a coloured stripe, at zero offset, and 24 dB of sideband suppression was required.

Thus with the most critical 'real' pictures found, the colour subcarrier component is the main source of interference and none of the offsets gives a clear advantage. For just-perceptible interference, the sideband suppression required is 24 dB at the image subcarrier frequency. The results give limited information about other frequencies but it is possible to conclude that the sideband suppression required is, at most, 14 dB.

3.3.2.2 Interference from the most critical test signals

With colour bars as the interfering signal, the most visible interference was coarse coloured patterning at zero offset. The interference was just perceptible at a sideband suppression of 30 dB. With Test Card G as the interfering signal, using a non-notched PAL coder, both the definition gratings and the colour bar stripe caused interference. The sideband suppression required was 32 dB for the 4.8 MHz grating and 25 dB for the 4.2 MHz grating (for a grating amplitude of 700 mV). The most visible interference from the colour bars in this case was fine luminance patterning and the sideband suppression required was 24 dB (for 75% amplitude bars).

With line sweep at zero offset, the patterning took the form of vertical lines. The interference was most visible where the sweep frequency was 5.5 MHz because the interfering side tone frequency was at its closest to the wanted vision carrier and the patterning was at its coarsest. The sideband suppression required was 33 dB. With line sweep at +5/3 line offset, coarse coloured parabolas were seen, centred where the sweep passed through 3.6 MHz (where the side tone was 4.4 MHz above the wanted vision carrier), and the sideband suppression required was 30 dB. Thus the sideband suppression required for critical test signals varies little with frequency. A typical value is 30 dB and the actual values are within ±3 dB of this.

A test was carried out with non-synchronised syncs and, of the video components outside the active picture, the burst caused by far the most visible interference. The sideband suppression required was 18 dB.

For completeness, the interference from full-field teletext (i.e. a teletext data waveform on each line of the picture) was also assessed, although this is not a critical signal. Coarse chrominance noise or streaking was seen at all three offsets. Vertical luminance stripes were seen at zero offset. The stripes arise from the vertical alignment of the data bits, and from the strong spectral components at multiples of one-eighth of the bit rate. The subjects differed regarding which type of interference was more visible and which was the most critical offset. The sideband suppression required was 11 dB.

It is thought that this selection of test signals covers the worst cases that can occur.

The visibility of interference from the lower sideband depends on the actual energy present in that region. Real pictures require less sideband suppression than critical test signals simply because the former contain less energy in the high-frequency region. The permissible energy in the lower sideband can be derived as follows (for a ratio of wanted to interfering vision carrier powers of +3 dB). Let us consider a critical test signal. The signal contains a tone whose amplitude is 700 mV peak-to-peak. This produces an upper side tone 17 dB below peak sync. The results show that about 30 dB of suppression of the lower sideband is required. Thus the energy in the lower sideband should not exceed a level of about 47 dB below peak sync.

4. DISCUSSION

The existing BBC specification for sideband suppression is shown in Fig. 12. (A lower limit originally specified at 2 MHz below the vision carrier frequency has recently been removed because it is now not thought that this will have a significant effect on the combined response of transmitter and receiver.) The specification was derived on a different basis from the work in this Report; in particular, a protection ratio of 16 dB for the median of four channels was assumed, which is not compatible with the value now used of 3 dB for the worst of the four channels. It was also intended to protect against worst-case interfering signals but the results reported here suggest that this is not necessary.

In drawing up a specification, it is necessary to take into account particular characteristics of television transmitters. The significance of this is shown by some measurements obtained from a high-power transmitter of recent design. The transmitter comprises two similar transmitters, 'A' and 'B', operating in parallel, and using separate vision and sound klystrons. To save electricity, the vision klystrons are pulsed, that is to say the beam current is reduced

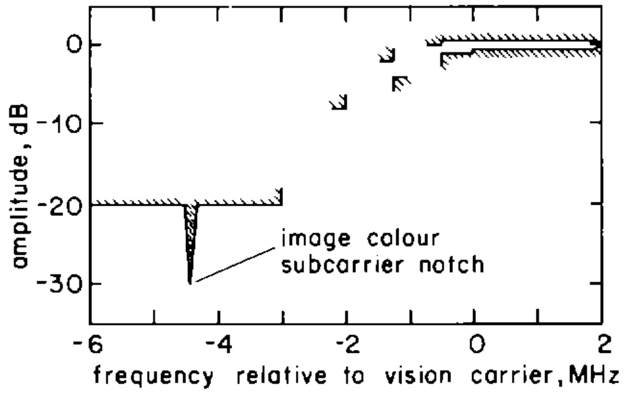

Fig. 12 – System I frequency reponse template (note test signal now recommended is 700 mV p-p tone on 350 mV pedestal).

during the intervals between sync pulses, when the saturation level need be no more than 0.5 dB above black level. Figs. 13 (a), (b) and (c) show the frequency response and sideband suppression measured with three different test signals. With the test tone at a low level, the amount of lift can be varied from near black level to near white level and it can be seen that the sideband suppression is much poorer near black level. This arises because the klystron characteristic becomes more curved as saturation is approached (and precorrection is ineffective outside the passband of the klystron). A high-level test tone

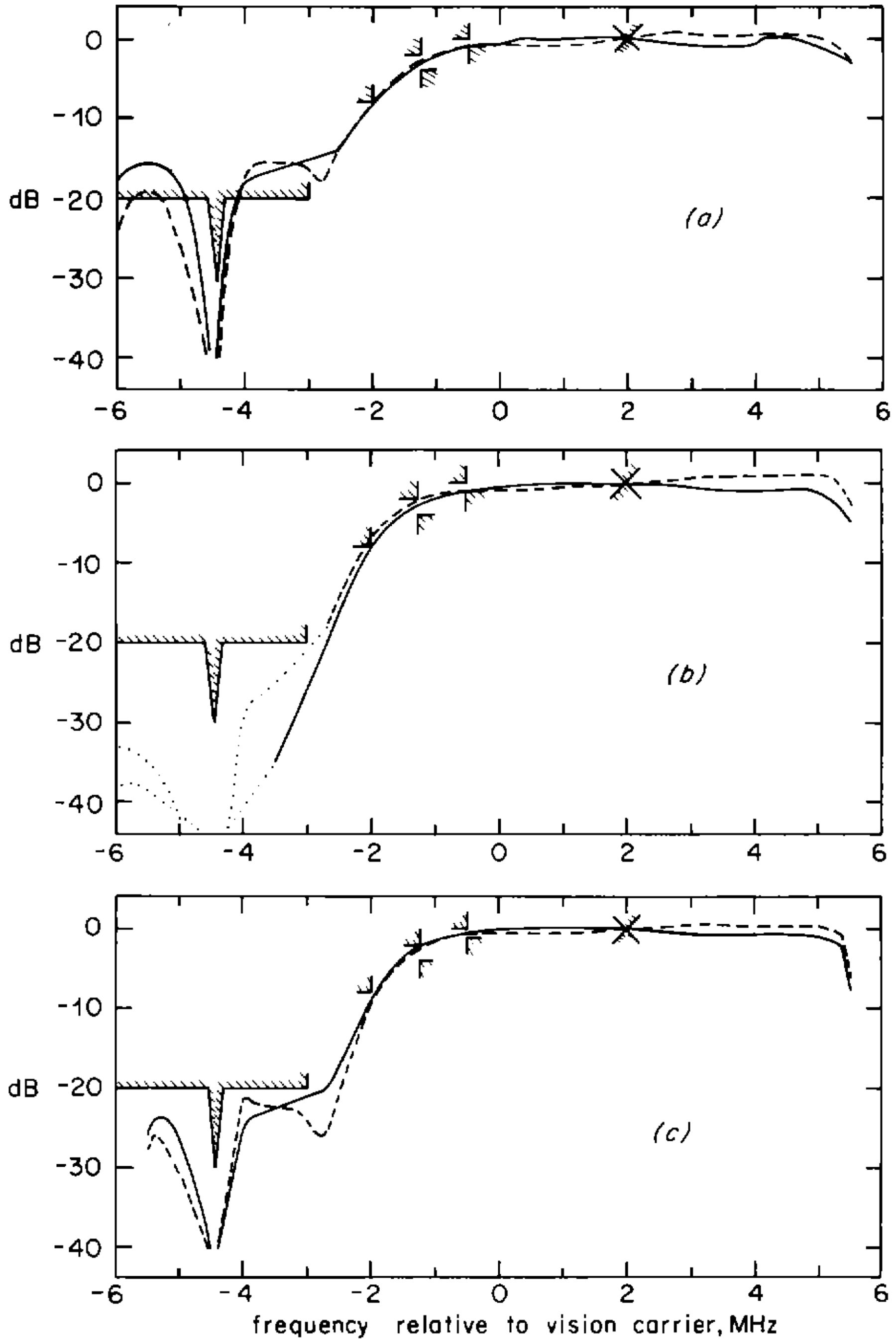

Fig. 13 - Frequency responses of A and B halves of a transmitter, measured with different test signals.

(a) With 200 mV p-p tone on 100 mV pedestal.
(b) With 200 mV p-p tone on 700 mV pedestal.
(c) With 460 mV p-p tone on 350 mV pedestal.

——— A - - - B

.... harmonics of syncs and blanking requires a mid-grey pedestal, and this test signal gives an intermediate amount of sideband suppression, 5 to 7 dB better than the worst case.

The test signal was not specified in Reference 1, but in transmitter designs of that time, the vision klystron ran in a linear but inefficient mode so the choice of test signal had less effect on the results, and the specification was easily met. BBC transmitter test specifications have prescribed a low-level tone near black level, but it is possible that there will be transmitters for which this is not the worst case. Therefore it is now recommended that the test waveform should be a 700 mV peak-to-peak tone on a 350 mV pedestal. This is a single, universal test signal appropriate to any transmitter design and it explores the whole of the transmitter's characteristic from white level to black level.

The subjective tests showed that for the worst pictures likely to be broadcast the sideband suppression required is 14 dB except in the image colour subcarrier region. It was clear that even critical pictures contain only relatively low levels of high-frequency components and hence the high-frequency components may be superimposed on any value of pedestal from near black level to near white level. Thus the worst-case sideband suppression of a transmitter may occur and, as noted above, this could be 6 dB worse than the value measured with the recommended test signal. Thus the sideband suppression required, when measured with a 700 mV tone, becomes 20 dB, in line with the existing specification.

For the image colour subcarrier, the suppression required was measured on a teletext page with 100% saturated colours and was found to be 24 dB. Here the recommended test signal is directly applicable and so an easing of the existing specification might be justified. However, it is not proposed that the specification should be changed. Other frequencies require less suppression than the image subcarrier and at a high-power transmitter it is more cost-effective to fit a high-power notch filter than to improve the linearity of the vision klystron. The use of image subcarrier notch filters is standard practice and a notch depth of 10 dB is easily achieved.

It follows from this discussion that the high-power transmitter whose performance is shown in Fig. 13 should not cause any interference.

5. CONCLUSIONS AND RECOMMENDATIONS

In this Report, the limit on lower sideband radiation from a television transmitter is set to ensure that the adjacent channel protection ratio is limited by the performance of domestic receivers. However, it is desirable to allow as much scope as possible for increasing the efficiency of transmitters. Too tight a specification would not improve spectrum economy (i.e. re-use in a network plan) but it would restrict transmitter efficiency.

To protect against worst-case interference about 30 dB of suppression of the out-of-channel portion of the lower sideband would be required. In practice a less stringent specification is sufficient to protect against interference from 'real' picture signals, including critical combinations of wanted and unwanted pictures.

It is recommended that the existing frequency response specification shown by the mask in Fig. 12 is appropriate and should be retained. However, compliance with the mask should be tested with a video signal of 700 mV peak-to-peak swept tone on a 350 mV pedestal.

The currently-accepted value of + 3 dB for the protection ratio for continuous upper-adjacent-channel interference is confirmed and should continue to be applied.

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